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POTENTIAL MODELING AND SIMULATION CONTRIBUTIONS TO AIR EDUCATION AND TRAINING COMMAND FLYING TRAINING: SPECIALIZED UNDERGRADUATE PILOT TRAINING - EXECTIVE SUMMARY

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This article recommends the development of certain modeling and simulation technologies as part of a modernization effort for Specialized Undergraduate Pilot Training (SUPT). Recommendations are based on a study conducted by the Aircrew Training Research Division of Armstrong Laboratory which was undertaken at the request of the Air Education and Training Command (AETC/XOR). The study's purpose was to assess current training challenges within SUPT to determine where modeling and simulation tools may offer solutions. Six primary problem areas were identified and analyzed, based upon extensive data collected during pilot interviews in a typical pilot training squadron. Based on findings, the study recommends specific technologies as solutions. Functional characteristics and applications of these technologies are described and discussed in the context of training effectiveness and efficiency.

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PREFACE

Modeling and simulation technologies are assuming increasing importance in Air Force training. Concepts, which only a few years ago were unknown or unaffordable, have appeared and matured. They have come none too soon, given the increasing need for tools that provide better training at less cost.

The present report deals with the application of modern modeling and simulation concepts to a specific Air Force training program. The report describes research conducted to determine the feasibility of meeting many current and future training requirements for Specialized Undergraduate Pilot Training (SUPT) through applied modeling and simulation concepts. The research was conducted by Armstrong Laboratory's Aircrew Training Research Division (AL/HRA), Williams Gateway Airport, in Mesa, AZ, at the request of the Air Education and Training Command (AETC/XOR). The work described here was intended as the first phase of efforts to identify training technology modernization needs across AETC.

The work was accomplished as part of the aircrew training research program at AL/HRA, Colonel Lynn A. Carroll, Division Chief, and Dr Dee H. Andrews, Technical Director. The research effort was conducted under Work Unit 1123-B2-13, Unit Level Training Research Applications (ULTRA), Dr. Bernell J. Edwards, Principal investigator.

POTENTIAL MODELING AND SIMULATION CONTRIBUTIONS TO AIR EDUCATION AND TRAINING COMMAND FLYING TRAINING: SPECIALIZED UNDERGRADUATE PILOT TRAINING - EXECUTIVE SUMMARY

INTRODUCTION

In 1994 the Air Education and Training Command (AETC/XOR) called for an analysis and evaluation of its flying training programs with a view toward training technology modernization. The Aircrew Training Research Division of Armstrong Laboratory (AL/HRA) was selected to conduct research to identify current and future training problems and challenges that could be met by the infusion of advanced modeling and simulation (M&S) technologies within Specialized Undergraduate Pilot Training (SUPT).

Rapid advances in modeling and simulation in the past few years have brought about affordable and effective tools for Air Force training applications. In many respects, the training concepts elaborated in this report are not new. Some have been recognized as desirable solutions for some time but technology has been lacking to enable their implementation. Now, however, newly emerging tools and techniques may open the way for farsighted, even revolutionary, concepts to become training realities.

LITERATURE REVIEW

The knowledge gathered to underpin the present effort came from various sources. Much was available from individual subject matter experts in various areas within the Air Force training community. Expert knowledge of training processes and programs came from managers, developers, and from pilots themselves. In addition, a large body of training and training research literature was surveyed. This included reviews of (a) current AETC documents describing plans, programs, policies, and practices of the SUPT program, (b) training research associated with undergraduate pilot training over the past 25 years, and (c) recent Air Force training modernization planning documents.

SCOPE OF ANALYSIS

The Air Force Chief of Staff recently stated that M&S technologies will play a significant role in advancing the power and impact of Air Force training at all levels. Earlier, the 1993 Simulator Four-Star Review and the Modeling and Simulation Four-Star Review clearly established M&S as indispensable elements in achieving Air Force training objectives. The Air Force recently established the Office of Modeling and Simulation within the Air Staff, demonstrating the commitment to the application of these technologies.

The authors of this report believe that the role of modeling and simulation will increase significantly in aircrew training programs. These tools will be applied not only to improve the fidelity and impact of training environments, but also to improve the dynamics of the instructional process.

AETC expects large-scale payoffs from technology infusion and they selected SUPT as the first program to be considered for M&S modernization.

From the outset of the present effort, there was mutual agreement between AETC and AL/HRA that a detailed needs assessment would reduce the risk that recommendations growing out of the research would become merely "Band-Aid" training solutions. The intent, therefore, was to implement systematic procedures for analyzing needs and identifying potential solutions. Two major questions emerged: (a) What are the major training challenges in SUPT?" and (b) "What technologies are available [or being developed] which can meet these challenges?"

METHOD

A team was formed within the laboratory to address these questions. It was comprised of pilots, research psychologists, and engineers. During the course of the effort, team members consulted a variety of experts including operations researchers, educational technologists, training managers, computer experts, and former military pilots.

The investigation followed a needs assessment model recommended by Kaufman (1991). Investigators developed a questionnaire in consultation with a number of subject matter experts. The questionnaire was designed to draw information from authoritative sources concerning the challenges and problems of training within SUPT. The 64th Operational Support Squadron (OSS) at Reese AFB was selected as the data collection environment because it was the only base at which the T-1 aircraft (in addition to the T-37 and T-38 aircraft) was operational at the time of the investigation. Investigators interviewed 28 instructor pilots (IPs) at the 64th OSS. They questioned pilots about specific challenges experienced in teaching student pilots, learning problems of students, perceptions of the training program, resources, management, and related issues. Answers given by IPs were recorded by interviewers for later analysis.

Content analysis procedures were used to tabulate and classify interview data. Findings from the interviews were also examined and correlated with SUPT training objectives and syllabus structure. Following analysis, findings were presented to Reese AFB instructors to verify interpretation of data and conclusions reached. Pilots confirmed the findings of the research team.

Description of Training Problems

In analyzing survey data, researchers identified and validated six training problem areas within SUPT. A brief description of each area is presented below.

Position Interpretation. This fundamental skill enables students to know where they are at any point during flight. Instructors say position awareness is one of the most difficult skills for novice students. They have trouble translating two-dimensional information from navigation instruments into three-dimensional flight geometry. Part of the difficulty arises from the age and design of the primary training aircraft, the T-37 itself. The student must interpret and correlate information from four different cockpit instruments, two of which are outmoded designs. Learning difficulties are further compounded by the multiplicity of tasks which occupy the pilot's attention during flight.

VOR/DME Fix-to-Fix Navigation. Navigating from Point A to Point B is a fundamental piloting skill. Like position interpretation, it is a three-dimensional concept that is difficult to learn using two-dimensional instrumentation. A major drawback is the lack of a suitable ground-based practice environment. Clearly, students need substantial practice integrating the perceptual and cognitive aspects of this task before attempting them in the aircraft. Students are often encouraged to practice these skills mentally, but it is difficult to do so without being able to visualize various instrument readings. Often, by the time students are able to hold a mental picture of the task needed for mental practice, they have largely learned to perform it in the aircraft.

Overhead Landing Pattern. This task is difficult to learn because it requires the novice pilot to perform a number of complex, integrated skills in rapid succession to safely land the aircraft. The student must master a repertoire of skills quite early in primary training in order to qualify for solo flight. Academic training plays an important role during introduction to the landing pattern, but students encounter difficulty integrating academic (cognitive) concepts with cockpit procedures. Instructors also find it hard to demonstrate some aspects of this task to students.

Formation Flight. Learning to maneuver an aircraft in close proximity to other aircraft involves development of precise hand-eye coordination skills. Pilots rely on specific visual references or cues to judge distance and closure with other aircraft. At present, most of these skills can be developed only in the flight environment because SUPT simulators lack sufficient visual display capabilities to support formation flight training. This results in the consumption of large amounts of jet fuel and instructor time while students accrue sufficient practice in the aircraft to master this task.

Low Altitude Flight. Like formation flight, low altitude flying requires precise control of the aircraft. It requires the ability to recognize critical visual information quickly and accurately. It also requires highly developed decision-making skills. The pilot must learn to manage the aircraft and perform a variety of mission-related tasks while at all times maintaining safe minimum altitudes. Current limitations in training for

this task stem largely from simulator inadequacies, i e., the visual display capabilities are inadequate to allow students to discriminate visual features such as ground objects and textural details for use as altitude cues.

Instructor Continuation Training. All instructors assigned to SUPT undergo an 8-week pilot instructor training (PIT) course at Randolph AFB, TX. During this course, instructors receive some training on how to instruct students. Part of this training involves familiarization with principles of the systematic approach to training (SAT) but, due to the brief span of the course, only a cursory treatment of these principles is involved. Student instructors receive relatively little training on diagnosing student learning problems and prescribing training activities. During interviews for this research, instructors tended to describe student learning problems mostly in terms of the inability to perform flying tasks rather than in terms of learning or instructional processes. This observation led investigators to believe that more explicit training in instructional processes would benefit instructors, students, and the program. There also appears to be no formal continuation training for instructors once they reach their assigned squadrons. Interview data suggests that experience, insights, and techniques informally shared among pilots may comprise a significant resource to IPs in learning to instruct students. While very desirable, all this will not teach an IP everything that is needed to excel as an instructor, nor will such shared training wisdom be complete or consistent. Therefore, increased formal and continuation training for instructors in these areas is highly recommended.

Technology Analysis

Prior to the pilot surveys, team scientists and engineers developed a preliminary list of available modeling and simulation technologies. Following completion of the training problem analysis, the preliminary list was reviewed, revised, and expanded. Our next step was to consider each problem area in view of various technology options. This process was accomplished using focus group and modified Delphi techniques to reach concordance among team members relative to the quality and likelihood of proposed technology-to-problem matches. The outcome of this process resulted in the following list of M&S technologies recommended for SUPT application.

MODELING AND SIMULATION TECHNOLOGY DESCRIPTIONS

Central Database System. This computer-based system is proposed as the functional center of the modeling and simulation technologies recommended for SUPT modernization. It will contain and manage simulation databases, learning resources, and student records. It will be accessible to students and instructors via various training hardware interfaces. The system will permit wide functional latitude to users. The system will also maintain a current profile or "picture" of individual learning performance and current status in the program. The central database system is relevant to all problem areas found in this research.

Large-Screen Displays. Large screen displays (LSDs) are electronic devices for projecting computer-generated imagery and digitized photography. An instructor pilot could use an LSD to display words, graphic material, figures, maps, videotape, videodisk, or CD-ROM content. The advantage of LSDs over other visual media is that they can support active learning processes instead of passive information viewing engendered by older media. With LSDs, students can interact directly with displayed information. LSDs have gained some acceptance in the last few years in classrooms in the military and elsewhere. However, this technology has progressed dramatically in recent years. High quality LSDs would be very affordable for SUPT, and the long-term technical forecast is favorable for cost-to-capability improvement. Training applications of LSDs extend to all SUPT academics areas, including many aspects of all problems areas identified in this report.

Computer-Assisted Instruction (CAI) Upgrades. The continued, rapid advance of computer technology represents the potential for large-scale improvements in computer-assisted instruction. Related to this potential are newer software concepts which may help improve the instruction provided by CAI. More efficient design methods are available to assess knowledge acquisition, assess student performance, and provide effective feedback within instructional software. Systems that integrate and manage a variety of multimedia options are now available and affordable. The outlook for this technology in training is positive. Moreover, it should enable increasing freedom and flexibility to students in managing their own training activities. These upgrades apply particularly to the position interpretation and fix-to-fix navigation training problems, but also extend to some aspects of other problems areas identified in this report.

SUPT Training Laboratory. The training laboratory would represent a new component in the SUPT program. It is recommended here as a needed learning environment to help students transfer academic knowledge to cockpit skills. Our analysis revealed a pattern in which students learn to correctly verbalize flight procedures but subsequently are unable to execute cockpit skills until they accrue considerable trial-error experience in the aircraft. The training laboratory would foreshorten this training lag by providing a practice environment for building basic hands-on skills, thus increasing training efficiency during in the simulator and aircraft phases.

Moreover, research shows that for some portions of training, students prefer, and benefit from, opportunities to experiment, discover, and practice independently of instructors. Students in groups of two or three, given a suitable practice environment, could generate beneficial learning synergy, in preparation for simulator and aircraft training.

The training laboratory would consist of medium-fidelity trainer cockpits in sufficient numbers for use by all students as needed. The visual flight environment would be displayed via large-screen displays or visor-mounted head displays. Students

could select varieties of training scenarios, and it would also be possible for instructors and students to modify scenario content to customize training as desired.

Training problem areas most benefited by this technology include position interpretation, fix-to-fix navigation, and portions of the overhead landing pattern. However, students could substantially improve proficiencies for all basic flying procedures by using the Training Laboratory.

Instructional Simulations. More powerful microprocessors have enabled the development of realistic, real-time simulations in traditional CAI formats. Instructional simulations could enable the combination of realistic task environments with automated feedback and guidance to the learner. Instructional simulation goes a significant step further than traditional CAI by permitting students to engage in dynamic tasks, such as operating avionics subsystems. Feedback is provided in various formats such as graphic displays or acoustic information. Instructional simulations can be used to build mental responses for many flying tasks prior to advanced training in a full-fidelity environment.

The following training areas would benefit from the application of instructional simulations: (a) instrument interpretation and radial geometry concepts, (b) position interpretation, (c) fix-to-fix navigation, (d) tasks involving on-line voice simulation of tower communications, i.e., flight planning, radio communications, etc., (e) overhead traffic pattern principles, (f) formation flight principles, and (g) low altitude flight orientations.

Helmet-Mounted Displays (HMDs). A helmet-mounted display is basically headgear with close-fitting lenses. Typically, the HMD is connected to a computer that generates visual images on two small screens positioned in front of the eyes. With magnification, lenses can display a visual environment which encompasses the normal field of human vision. Since the viewer is visually "separated" from the actual surroundings and sees only imagery provided through the system, the effect is referred to as "virtual reality."

Some HMD visual systems are capable of simulating three-dimensional imagery which can appear fairly realistic to the viewer. Several technical approaches are used in designing HMDs for three-dimensional effects which involve offsetting the images presented to each eye to produce depth or dimensional effects. Other HMD designs provide monocular imagery which can be useful for many training purposes and is somewhat less costly than systems with binocular capabilities. Aside from depth perception effects, other advantages of HMDs include compact system size, ease of use features, full-field of view, and potentially high quality imagery. The long-term outlook for growth of HMD technical capabilities is very positive with corresponding decreases in cost expected.

HMDs should prove effective for certain aspects of training for position interpretation (awareness), the overhead landing pattern, formation flight, and low

altitude flight. Virtual environments employing HMDs would enable students to explore the spatial characteristics, dimensional relationships, and specific visual cues associated with these tasks from an infinite variety of eye points in simulated space. Such refinements in visual training have not been available in SUPT. Probably the major benefits from these enhancements would come during familiarization training, including the increased ability of students to develop effective mental models of complex flying tasks.

Three-Dimensional Projections. Several technologies are available which provide three-dimensional visual effects without using HMDs. These displays employ various screen configurations. Some require the viewer to use specially designed glasses. The optical principle used in HMDs (offsetting the imagery to each eye) is the same employed for these displays. Several technical approaches are used to achieve it, including polarization, image opaqueing, and alternate video frame scanning. The capabilities of three-dimensional displays appear to hold instructional advantages for all of the problem areas identified in this report. As one example, the objective might be to have students gain skill and speed in determining aircraft position, i.e., orientation. A three-dimensional display would permit students to study aircraft position from an infinite variety of eye points thus expanding spatial awareness.

Unit Training Device (UTD). This device will provide high fidelity aircraft simulation at very low cost. The UTD would offset current simulation training deficits in SUPT by providing affordable simulators in sufficient numbers for use by all students, as needed, without time restrictions. UTDs would be capable of training all aspects of SUPT. Training transfer to the aircraft should be high and thus permit students to develop skills to high levels of proficiency prior to aircraft sorties. The UTD would contain a high fidelity cockpit with all systems functional. Engineering design and manufacturing techniques already available would keep unit production costs low. The trainer could be operated by an instructor with student, or by the student alone, via user-friendly control interface. The UTD would be compact, easily transportable, and could operate in standard office environments without augmented power, cooling, or the presence of support personnel. UTDs, combined with the Display for Advanced Research and Training, or DART technology, described below, would constitute a powerful, economical simulation package with substantial training benefits to SUPT. Specific applications are discussed below in the DART description.

Display for Advanced Research and Training (DART). This technology would provide the visual flight environment for the UTD, but could also be used with other simulator cockpits. An integral component of the DART is a highly capable image generator which drives Barco rear-screen mounted projectors producing a real-time visual flight environment with excellent color, resolution, and wide field-of-view characteristics. DART technology has high evolutionary potential, and the industrial forecast for stability and life cycle are long term. All of the training problem areas identified in this report would benefit substantially from the UTD/DART combination. Moreover, virtually all areas of the syllabus could be improved using this device. This

prediction is based upon the critical role of high fidelity visual display systems in simulation-based pilot training.

Simulation Networking Technologies. Simulator networks in two- or four-ship configurations would employ local area network (LAN) technology. In minimal (two-ship) configuration, networking would provide highly capable flight environments for instructor-student (or lead-wingman) in separate aircraft. This would provide training capabilities for a full range of two-ship missions, specific syllabus events, or component skills practice, as desired. Each simulator would provide highly realistic representations of the other aircraft. In an expanded configuration, training could accommodate complete four-ship training sorties and exercises. Specific types of training supportable via networking include the following: (a) formation flight: aircraft control skills (closure rate and techniques), aspect angle and heading crossing angle, co-altitude rejoins; (b) traffic pattern scenario rehearsal: one aircraft in pattern, multiple aircraft in pattern, emergency aircraft recovery, confused tower; and (c) multiship mission rehearsal practice (all aspects) prior to aircraft sortie.

Enhanced formation flight training for all three SUPT aircraft appears feasible. Optimal phasing of technology acquisition would be based on determining which aircraft training programs should be supported by networking. The forecast for this technology is for continuing cost decreases, so eventual inter-base simulator networks would be feasible. Obviously, such capabilities go beyond current training requirements. However, this technology could afford AETC the opportunity to train to higher levels than in the past. It would appear particularly appropriate for the Introduction to Fighter Fundamentals (IFF) Course which follows SUPT. For example, student pilots selected for fighter aircraft assignments would have a substantial advantage in acquiring basic fighter maneuvering (BFM) skills if multiship simulation capabilities (networked UTDs) were available in the IFF course.

As a research and development (R&D) agency with considerable experience in distributed interactive simulation (DIS), AL/HRA is in a favorable position to recommend multiship simulation applications. The feasibility of networking technology required for SUPT application is now well within the state-of-the-art, so that technical risks in implementing this technology are low.

Electronic Kneepad. Instructors must record observations about student performance during training flights. But, notations can only be written as time permits while the instructor is monitoring the student and the aircraft. Notebooks fastened to a kneeboard (the traditional equipment) leave much to be desired in terms of efficiency and convenience. The recommended solution technology is a kneepad-like electronic device which functions something like a hand calculator. It would require only a few keystrokes to record information about student performance using a "shorthand" coding system. Data would interface with an Aeronautical Training Recorder (described below) for later use in debriefings. The electronic kneepad would be useful in all phases of

simulator and aircraft training, simplifying the workload of the instructor and improving the quality and quantity of performance feedback to the student.

Aeronautical Training Recorder (ATR). The Aeronautical Training Recorder would enable IPs to capture a continuous sequence of information from aircraft systems for use in recreating training flights via simulation. The ATR would consist of three major parts: (a) an on-board, high capacity microcomputer with data storage linked to all aircraft subsystems, controls and communications; (b) an on-board global positioning system (GPS) linked to the on-board computer; and (c) a ground-based graphics computer that would combine flight data with a local terrain database to simulate the training flight. Of all technology applications proposed during this research, the ATR was identified by instructor pilots as having the greatest training impact on SUPT students. In large measure this is because of the importance of providing accurate and timely performance feedback to student during debriefings. The ATR as conceptualized would provide the critical link in allowing students to see recreations (recorded data) of critical events and situations during aircraft sorties.

TRAINING TECHNOLOGY INVESTMENT ROADMAP

The roadmap on Figure 1 presents an overview of the SUPT Training Technology Investment Strategy recommended in this report. In the roadmap, analysts have summarized and grouped technologies into integrated program timelines. The overall developmental period spans fiscal years FY1995 through FY2020. There are four principal areas of development. Technologies recommended in this report are subsumed under each of these areas:

1. **Advanced Simulation Technologies** which includes the UTD and DART work in parallel development.

2. **Database Modeling** which includes the central database, the instructor pilot data entry system, and the aeronautical training recorder technology.

3. **The SUPT Training Laboratory** development which includes the integration of several display systems including LSD and HMD technologies, as well as computer-assisted training upgrades.

4. **The Electronic Classroom** program which will involve the development of various computer-based and visual display technologies recommended in this report.

SUPT Training Technology Investment Strategy
Overview Roadmap

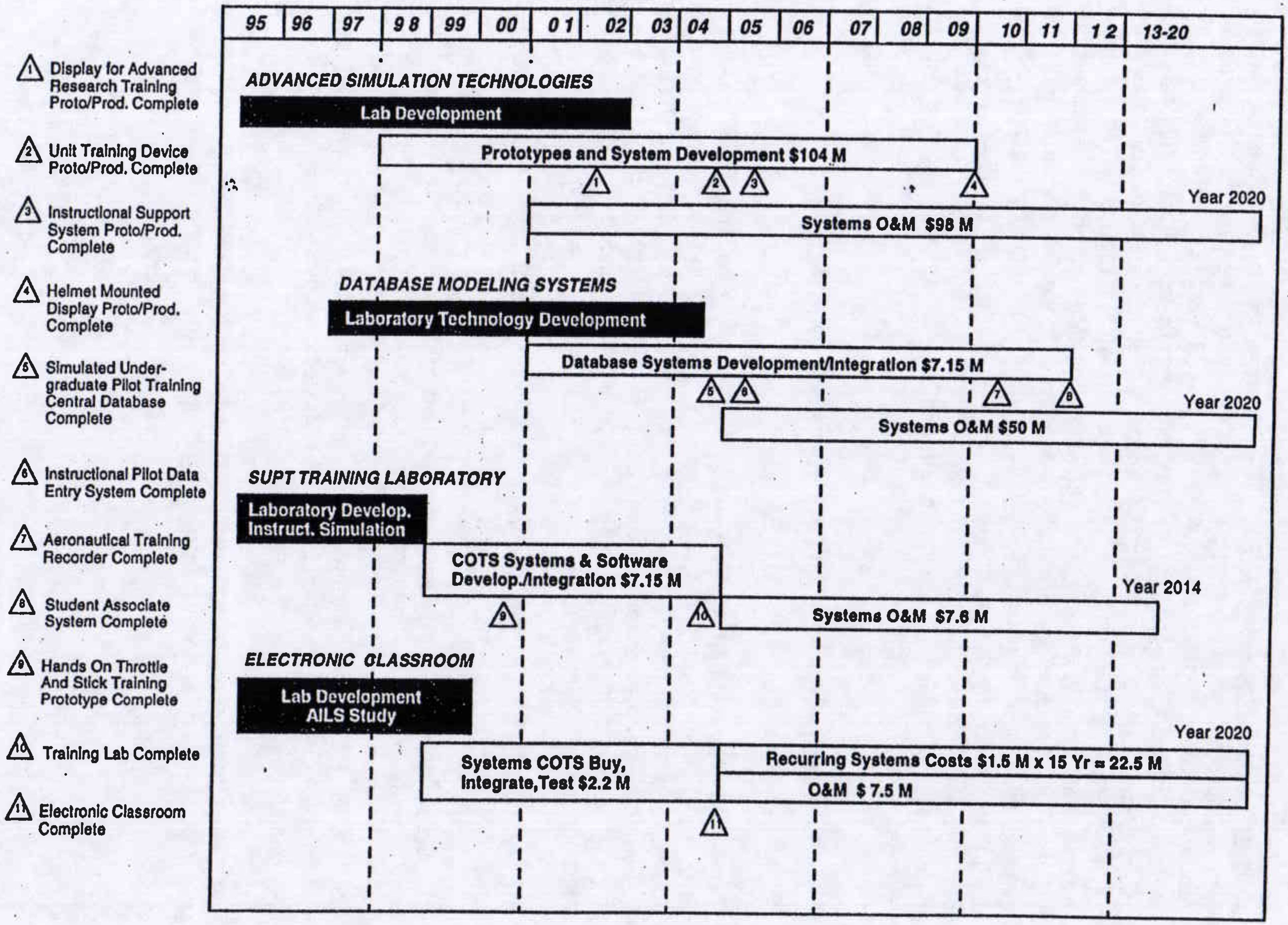

Figure 1

SUPT Training Technology Investment Strategy
Overview Roadmap

Each program is divided into three phases (shown in grouped time lines or boxes): laboratory development (shown by the shaded areas); prototype development and production, or systems development/integration phases; and systems operating and maintenance (O&M) phases, which extend to FY2020. Estimated funding requirements are contained within the appropriate boxes. The small triangles indicate estimated completion dates for various milestones in programs.

The investment strategy which the roadmap conceptualizes is intended to maximize training payoffs to SUPT. Advanced simulation capabilities are projected for the shortest lead time into the program. Much of the technology foundations to support UTD and DART devices are already ongoing at AL/HRA with evolutionary upgrading to be transitioned into the SUPT prototypes as soon as funding programs allow. With this prospect, major training benefits from advanced simulation devices can impact SUPT at the earliest possible time.

Database modeling technology, SUPT Training Laboratory, and Electronic Classroom technologies will all enhance training effectiveness and efficiency in the total program. Substantial lead-in development work is still necessary on the part of AL/HRA for these areas, however. Seminal work in instructional simulation is ongoing, and electronic classroom media systems development is planned by AL/HRA for FY96 start-up.

A more detailed description of this investment strategy, including roadmaps for each of the four principal technology areas, is contained in Andrews et al (1995).

PRELIMINARY COST-BENEFITS MODEL

As an adjunct to the research summarized in this report, work was begun on a cost-benefits model to be used in assessing potential training benefits from new modeling and simulation technologies. As a result of the effort, a preliminary cost-benefits model was developed. When the model has been completed and validated, it should provide a effective tool for use by training program planners and managers in assessing long-term benefits from specific applications of training technologies. A more detailed description of the preliminary model and its development is contained in Andrews et al (1995).

CONCLUSIONS

We believe the modeling and simulation technologies described in this report can improve SUPT in general, and the six identified training problem areas in particular. While these six areas were the ones most often mentioned in the interviews, they were not the only areas of need described by IPs during interviews with researchers. It is important to recognize that acquiring these technologies would benefit many, if not all, areas in the SUPT syllabi.

A key issue is how these technologies could be added and integrated into the existing programs given the "fullness" of the current SUPT syllabus. We assume syllabus length would not be expanded merely to accommodate training innovations. However, we are confident that all of the recommended technologies would be capable of generating sufficient training efficiencies to more than offset their implementation. Efficiencies would result from replacing less efficient existing methods and reducing training loads in general.

Another important issue is the contribution of technology to improve student progress in the program, as well as the potential for raising the general level of student achievement. Our analysis leads us to believe that these M&S tools would enable SUPT to move beyond the advancement of students in the program based solely upon a group-determined pace. Rather, students would advance individually as they meet prescribed performance criteria. By this, we are not advocating exclusive self-paced progress. As experience shows, that method can produce students who finish so fast or so slow that program processes cannot be accommodated. Instead, students would progress individually within blocks of training. Those finishing at a faster rate would engage in advanced training activities until the group completes the block. This would encourage pilots to perform all phases of training to the best of their abilities. It would also reward superior achievers with additional opportunities to excel.

This report has described Phase I of AL/HRA's Modeling and Simulation R&D effort. Phase II is anticipated as applying the same analytical methodology to other AETC flying training programs. Phase II is expected to target "schoolhouse" applications of M&S within selected combat crew training systems (CCTS) programs. It is also anticipated that some of technologies identified for SUPT may benefit CCTS.

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